A New Fast and Robust Circle Extraction Algorithm

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Abstract

This paper presents a new algorithm that is capable of extracting circles from complicated and heavily corrupted images. The algorithm uses a least-squares fitting algorithm for arc segments. The arcs are segmented by using the short straight lines which are extracted by a fast line extraction algorithm. The arc segments are used to yield accurate circle parameters. Tests performed on synthetic and real-world images show that the algorithm quickly and accurately extracts circles from complicated and heavily corrupted images.

1 Introduction

Extracting circles from digital images has received much attention for several decades in computer vision. Therefore, many algorithms have been presented. The Hough transform (HT) is the best known algorithm. In spite of its popularity owing to its simple theory of operation, the HT has some problems. We point out, for instance, the computational burden in the 3-dimensional parameter space. To solve these problems, several modified algorithms have been proposed based on the HT [1, 2, 3, 4, 5]. However, the improvements still have some problems such as the choice of thresholds, finding peaks in the parameter space, interference from abundant edge pixels, and poor tangents and gradients of the edge pixels.

On the other hand, several algorithms which do not use histograms in the parameter space have been presented such as a least-squares fitting algorithm [6], an algorithm using geometrical symmetry properties [7], circle extraction using a genetic algorithm [8] and the UpWrite [9]. These non-HT-based algorithms may extract circles faster that the HT-based algorithms because they do not use histograms in the parameter space.

All the above mentioned algorithms process the image pixel by pixel. Thus, they sometimes fail in the following situations:

- The circular objects are embedded in a complicated background.
- The input image has many extraneous edge pixels.
- The input image is heavily corrupted.

These situations interfere with the construction of a robust histogram in the parameter space as well as the pairing of edge pixels used for the estimation of circles for HT-based and non-HT-based algorithms.

In the work presented here, a new circle extraction method is proposed which does not need a parameter space. It fits short straight lines to a circle by least-squares. The short straight lines are determined by using a fast line extraction algorithm [10]. This is possible because circles are represented as short straight lines in digital images. Also, the line-fitting approach can be used to improve the accuracy and speed of the algorithm in complicated and heavily corrupted images.

2 Algorithm description

2.1 The least-squares fitting algorithm

The least-squares fitting algorithm is one of the most commonly used methods for finding the circle parameters $(\tilde{R}, \tilde{x}, \tilde{y})$. We review this algorithm given in reference [6]. Given a set of pixels $(x_1, y_1), \ldots, (x_N, y_N)$ which represents a contour that is assumed to belong to a circular arc, we use the least-squares fitting algorithm to approximate the curved segment defined by the N pixels. The arc center $(\tilde{x}, \tilde{y})$ and radius $\tilde{R}$ are estimated by minimizing the sum of the squared errors between the radius and distances from the pixels to the center.

$$min \quad e(\tilde{R}, \tilde{x}, \tilde{y}) = \sum_{i=1}^{N} [R^2 - \{(x_i - \tilde{x})^2 + (y_i - \tilde{y})^2\}]^2$$

Setting to zero the partial derivatives of $e(\tilde{R}, \tilde{x}, \tilde{y})$ with respect to $\tilde{R}, \tilde{x}$ and $\tilde{y}$, we obtain [6]

$$\tilde{x} = \frac{c_1 b_2 - c_2 b_1}{a_1 b_2 - a_2 b_1} \tag{1}$$

$$\tilde{y} = \frac{a_1 c_2 - a_2 c_1}{a_1 b_2 - a_2 b_1} \tag{2}$$